U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

Successes

SO_3 Emission Control Technology for Coal-Fired Power Plants

ADVANCED RESEARCH

To support coal and power systems development, NETL's Advanced Research Program conducts a range of pre-competitive research focused on breakthroughs in materials and processes, coal utilization science, sensors and controls, computational energy science, and bioprocessing—opening new avenues to gains in power plant efficiency, reliability, and environmental quality. NETL also sponsors cooperative educational initiatives in University Coal Research, Historically Black Colleges and Universities, and Other Minority Institutions.

ACCOMPLISHMENTS

- ✓ **Process innovation**
- ✓ **Cost reduction**
- ✓ **Greater efficiency**
- ✓ **Environmental benefits**

Introduction

With support from the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), the Energy & Environmental Research Center (EERC), along with Marsulex Environmental Technologies and the ALSTOM Power Inc. Air Preheater Company, has been working to develop solutions to sulfur trioxide (SO_3) emission problems in coal-fired boilers. A significant pollutant in its gaseous form, SO_3 is the primary agent in acid rain and a precursor to sulfuric acid (H_2SO_4).

To meet the specific reductions in sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions required by the 1990 Clean Air Act Amendments, coal-fired electric utility emission reduction strategies have included installation of flue gas desulfurization (FGD) systems for SO_2 control and selective catalytic reduction (SCR) technology for NO_x control. However, while reducing SO_2 and NO_x, these technologies have increased the potential for emission of SO_3 and sulfuric acid aerosols and, in turn, increased stack opacity (a measure of particulate emissions). The reasons are clear: 1) FGD systems allow power plant operators to fire cheaper high-sulfur coals, which generate more SO_3 than do more expensive low-sulfur coals. While effective for SO_2 capture, wet FGD has been shown to have a minimal effect on removal of SO_3; and 2) SCR for NO_x control results in increased SO_3 concentrations in the flue gas as a result of catalytic oxidation of SO_2 by the SCR. The problem may be aggravated by fine particles formed by the reaction of SO_3 with excess ammonia present from the FGD or SCR process, resulting in a highly visible "blue plume" emitted from the stack.

Technical Approach

The basis of the SO_3 reduction technology being demonstrated by the EERC and its partners is to provide controlled condensation of SO_3 by injection of fine particles immediately upstream of the air preheater (APH). The particles provide nucleation sites for heterogeneous condensation in preference to homogeneous condensation and condensation on metal APH surfaces. The condensation process does not depend on the composition of the particles, but only on the particle-size distribution and particle concentration. Limestone was chosen for its low cost and its ability to provide a degree of acid neutralization after condensation has occurred.

A computer model developed by the EERC determines the amount of SO_3 transformations and interactions across an APH to assist in developing strategies to minimize the level of SO_3 released to the environment. The predictive model developed by the EERC utilizes 1) an ash

Project 1:

Evaluation of SO_3 Emission Control by Flue Gas Humidification at the R. Paul Smith Station

Duration

Start Date: 04/01/2001

End Date: 06/30/2002

Cost

Total Project Value
$244,000

DOE/Non-DOE Share
$97,500 / $146,500

Project 2:

Modeling the Interaction of Vapor-Phase and Particulate Species at Low Temperatures

Duration

Start Date: 04/01/2001

End Date: 08/31/2002

Cost

Total Project Value
$100,000

DOE/Non-DOE Share
$40,000 / $60,000

Project 3:

Modeling of Limestone Injection at Chesterfield Unit 5

Duration

Start Date: 07/01/2005

End Date: 09/30/2005

Cost

Total Project Value
$32,043

DOE/Non-DOE Share
$10,813 / $21,230

Partners

Energy & Environmental
Research Center (EERC)
Grand Forks, ND

Marsulex Environmental
Technologies, LLC
Lebanon, PA

formation model to predict the particle loading and properties (particle-size and composition distribution [PSCD]) of particles entering the APH, 2) FLUENT™ computational fluid dynamics (CFD) software to predict velocity and temperature profiles, and 3) Chemkin™ reaction kinetics software to predict the rate of SO_3 formation in the gas phase. The EERC model employs algorithms to account for heterogeneous condensation of sulfuric acid on ash particle surfaces as well as on metal surfaces, to predict particle impaction and accumulation rates in the APH and, finally, to predict the gas-phase SO_3 concentration at the entrance to the electrostatic precipitator (ESP).

The results of the modeling work indicated a significant reduction of SO_3 in the presence of fine particles less than approximately 5 µm in diameter as the flue gases containing SO_3 passed through the APH and ductwork upstream of the ESP, which was corroborated by early field observations at a full-scale utility boiler. This finding provided a unique opportunity to reduce the level of SO_3 in the flue gas as it passes through an APH.

Demonstrations

The site selected for a full-scale demonstration of the technology was Dominion Energy's Chesterfield Station Unit 5, located in Chester, Virginia. The plant is a nominal 350-MW unit firing 183,000 lb/hr of a bituminous coal. The unit is equipped with SCR technology and cold-side ESPs. Unit dimensions and operating data were obtained to model the expected degree of SO_3 reduction using the technology.

The researchers modeled the process in three phases for the unit firing the current baseline coal (current coal) and for a higher-sulfur coal contemplated for future use:

- The first phase involved prediction of fly ash size and composition distributions. The chemical and physical transformations of the inorganic components of coal to ash or slag during combustion depend on the design of the system, operating conditions, and fuel composition. During the combustion and gas-cooling process, the inorganic species are transformed into inorganic vapors, liquids, and solid particles in the initial combustion phase. These ash precursor materials are cooled as they are transported with the bulk gas flow through the combustion system. The model uses advanced coal inorganic constituent analysis, boiler parameters, and a detailed knowledge of the chemical and physical transformations of inorganic components during combustion to predict the particle size and chemical composition of the resulting ash. An aerosol formation and evolution model component predicts submicron ash formation by homogeneous nucleation and growth by heterogeneous condensation and coagulation.

- The second phase was to determine the flue gas components at the entrance to the APH, particularly SO_2, SO_3, H_2O, and H_2SO_4. A simple calculation produced an estimate of gas composition at the furnace exit based on the coal chemistry, coal feed rate, and excess air. Since measurements of SO_2 and SO_3 concentration after the SCR at the APH entrance were available for the current coal, these were used rather than determining SO_3 concentration from kinetic modeling. For the high-sulfur coal, the researchers assumed that the SO_2 concentration and conversion to SO_3 across the SCR would be proportional to that of the current coal.

- In the third phase, FLUENT—a CFD code—was used to model flow patterns through selected devices. The CFD model provides the flow of gas-phase and particulate-phase materials along with the velocity and temperature distribution through the APH and downstream ductwork. This determines the impacts of species mixing and impingement on the walls of particles suspended in the flue gas streams. The model outputs are then used to model the particle transport and deposition processes. When combined with an ash impaction and sticking model, this information determines the impacts of particles as well as particle sizes on the fate of SO_3 in the APH and ductwork between the APH and the ESP.

A full-scale field demonstration using the technology evaluated within this project was performed during late summer 2006. A commercial SO_3 generator that the plant uses for ESP conditioning was used to catalytically generate an elevated SO_3 concentration that was anticipated to result from firing a higher-sulfur coal (~35 ppm SO_3) with an SCR installed. The control technology used finely ground limestone injected immediately ahead of the APH as the SO_3 removal medium. Precise placement of 12 limestone injection lances provided a reasonably even distribution across the gas stream going into the APH.

SO_3 sampling was performed at three locations: 1) the inlet to the APH (after the SO_3 injection location), 2) the exit of the APH, and 3) the inlet to the ESP. The sampling was done at the APH inlet and outlet locations and at the ESP inlet using the controlled condensation method. The measured SO_3 levels in the flue gas during the tests are shown in Figure 1. There was a 53.6 percent average reduction in SO_3 (as measured at the ESP inlet location) as a result of limestone injection. No increase in APH pressure drop was observed, and there was no change in ESP performance or increase in stack opacity during the limestone injection.

From the model predictions, the calculated SO_3 removal results for the currently fired coal with an assumed SO_3 concentration of 36 ppm are shown in Figure 2 in comparison with the measurements obtained during the test program. At the ESP exit, a substantial reduction in gas-phase SO_3 was predicted for the case with limestone injection (25 versus 55 percent of the starting concentration) with the difference condensed on particulate material. Although the limestone only increases the particle loading from 1.5 to 3.0 to 4.0 percent, the small particle size results in significant additional condensation. The full-scale test results were in good agreement with the model predictions.

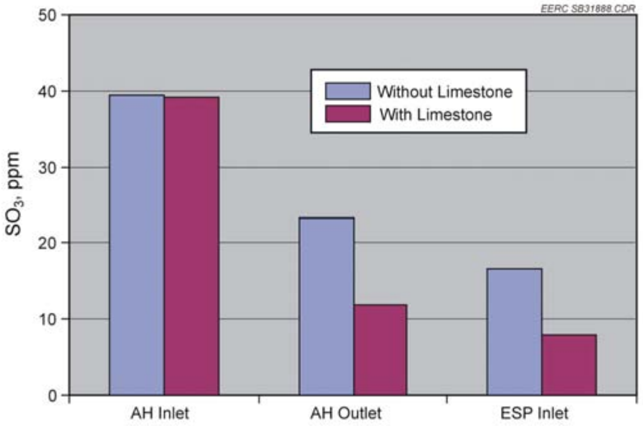

Figure 1. Measured SO_3 levels in the flue gas.

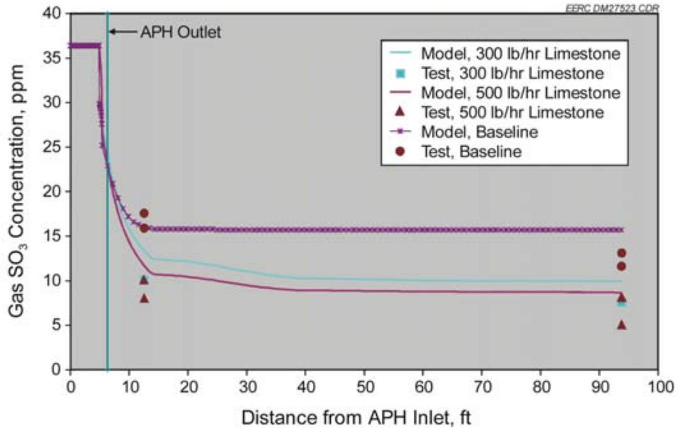

Figure 2. Calculated SO_3 removal results compared to actual SO_3 removal.

Commercial Opportunity

Improved sulfur control technologies such as an FGD combined with a fabric filter baghouse make possible the burning of higher-sulfur coals. However, reduction of SO_3 concentrations to less than a dew point temperature of 270°F is then required to avoid back-end corrosion, damage to fabric filters, and visible stack emissions. The operating criteria for the SO_3 control technology imposed the requirements of having no negative effect on unit operations, such as increased APH pressure drop or accumulation of material in the ductwork; high levels of reliability, operability, and maintainability; low operating cost; and a reasonable capital cost. All of these requirements are met using this SO_3 reduction technology. Other SO_3 abatement technologies—such as the use of fireside reagents, reagent-based postcombustion additives, and wet ESP technology—do not meet all of these desired performance and operating requirements.

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